UCSB HYPERLOOP

University of California, Santa Barbara

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INTRODUCTION

- Follow along at **ucsbhyperloop.com/dw**
- 21 senior engineering undergraduates working to build and test a pod at Competition Weekend
- Emphasizing cost-effectiveness, scalability, and feasibility
- Estimated cost to complete design: $40,000
    - Funding/resources already raised:
        - $5,000 from Ingersoll Rand
        - $5,000 from Raytheon
        - $5,000 from private donors
        - Electronics donated by NXP Semiconductors
    - **~$25,000 to be raised**

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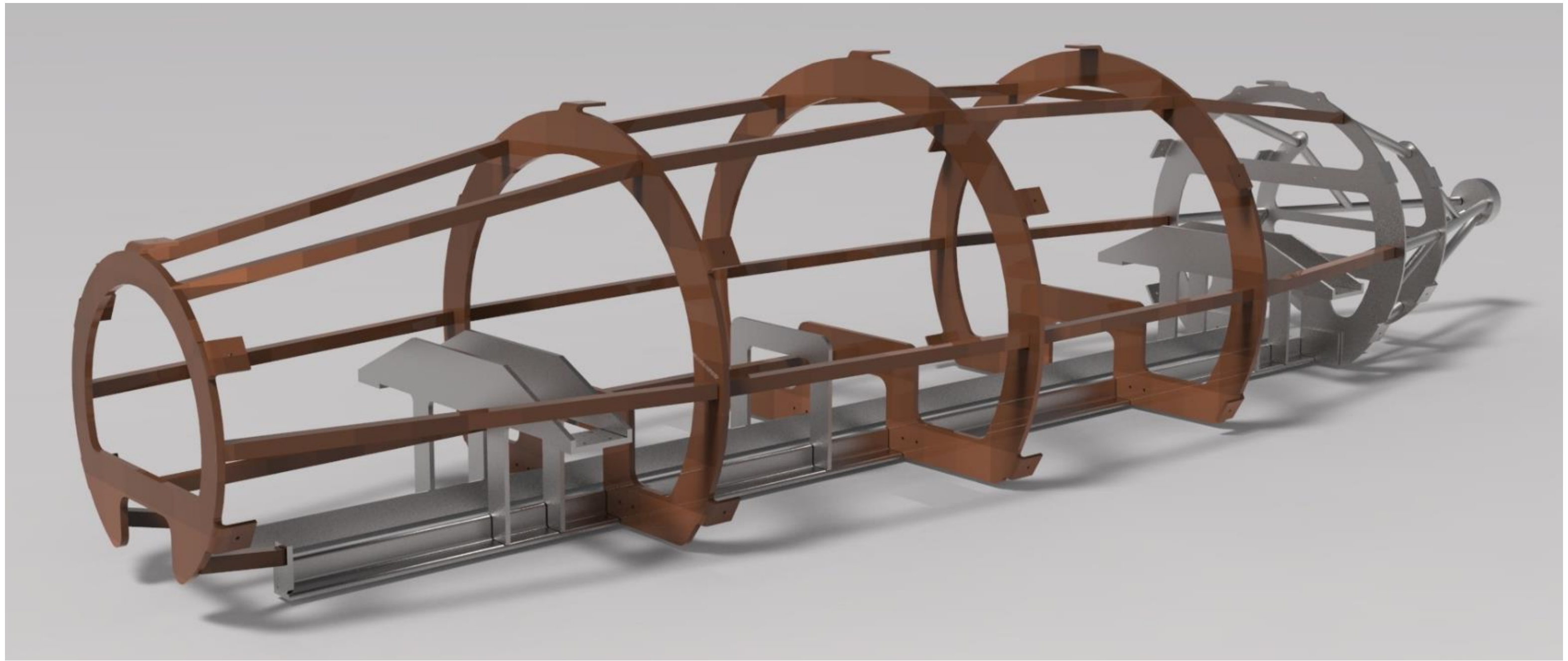
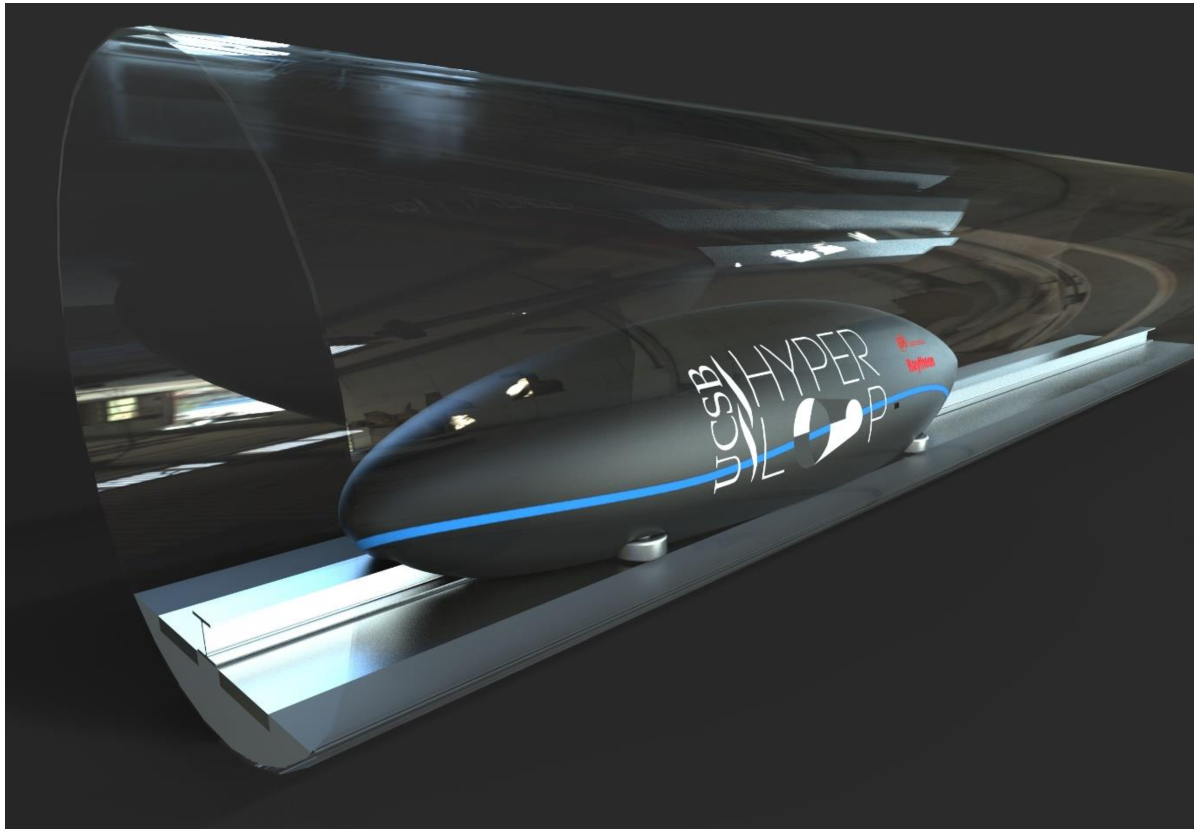
FRAME

- 13’7” (length) x 3’4” (width) x 2’7” (height)
- Divided into front, base, and rear frame
  - Lightweight, wooden front frame reinforces shell
  - Aluminum base frame supports all major subsystems
  - Steel tube rear frame interfaces with SpaceX pusher



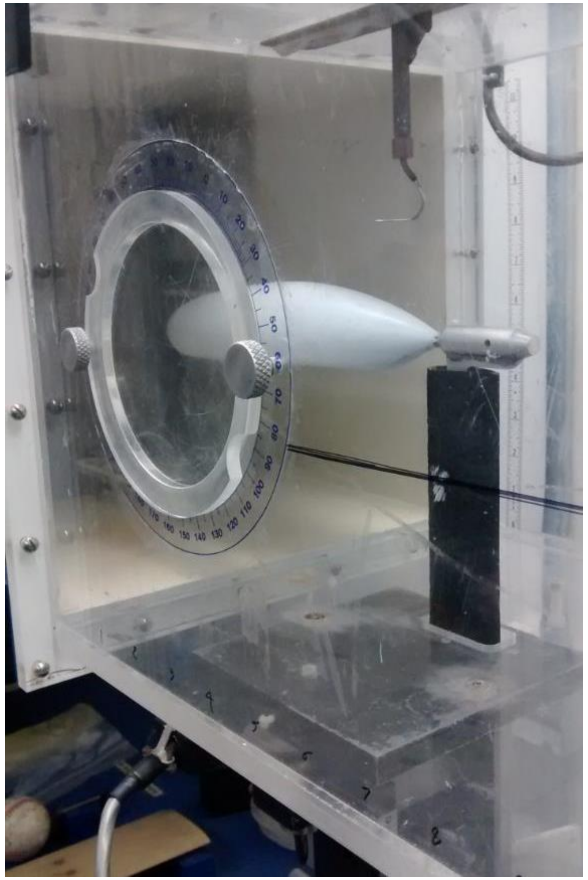
SHELL

- Tapered bullet shape
- E-Glass reinforced polyester
  - Uniformly strong in all directions



WIND TUNNEL TESTING

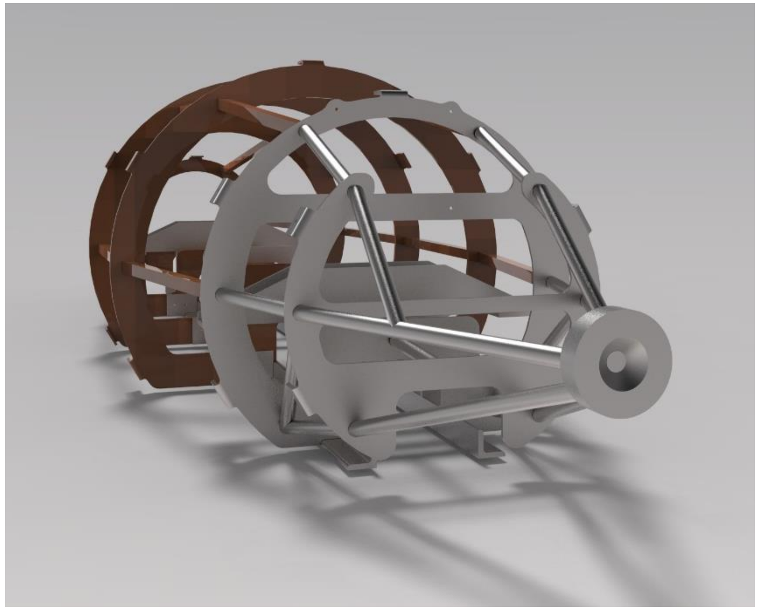
- 3-D printed ABS plastic pod model
- Reynolds number in evacuated tube is 8.5×10^3
- Estimated drag coefficient = 1.5
  - Drag force at 0.02 psi = 1.5 lbs

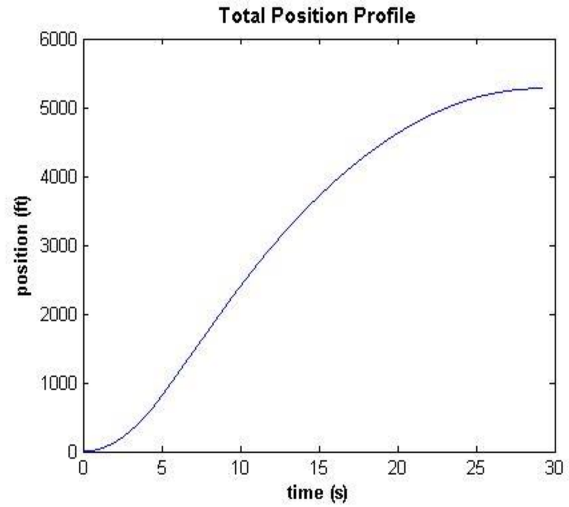


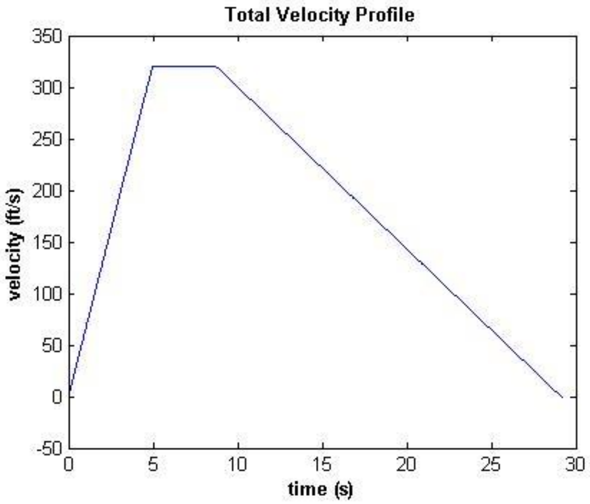
Pod model mounted in wind tunnel

TRAJECTORY

- Top speed of 218 mph (320 fps)
- Total run time of 29.16 s
  - Acceleration – 4.98 s
  - Coasting – 3.75 s
  - Braking – 20.43 s

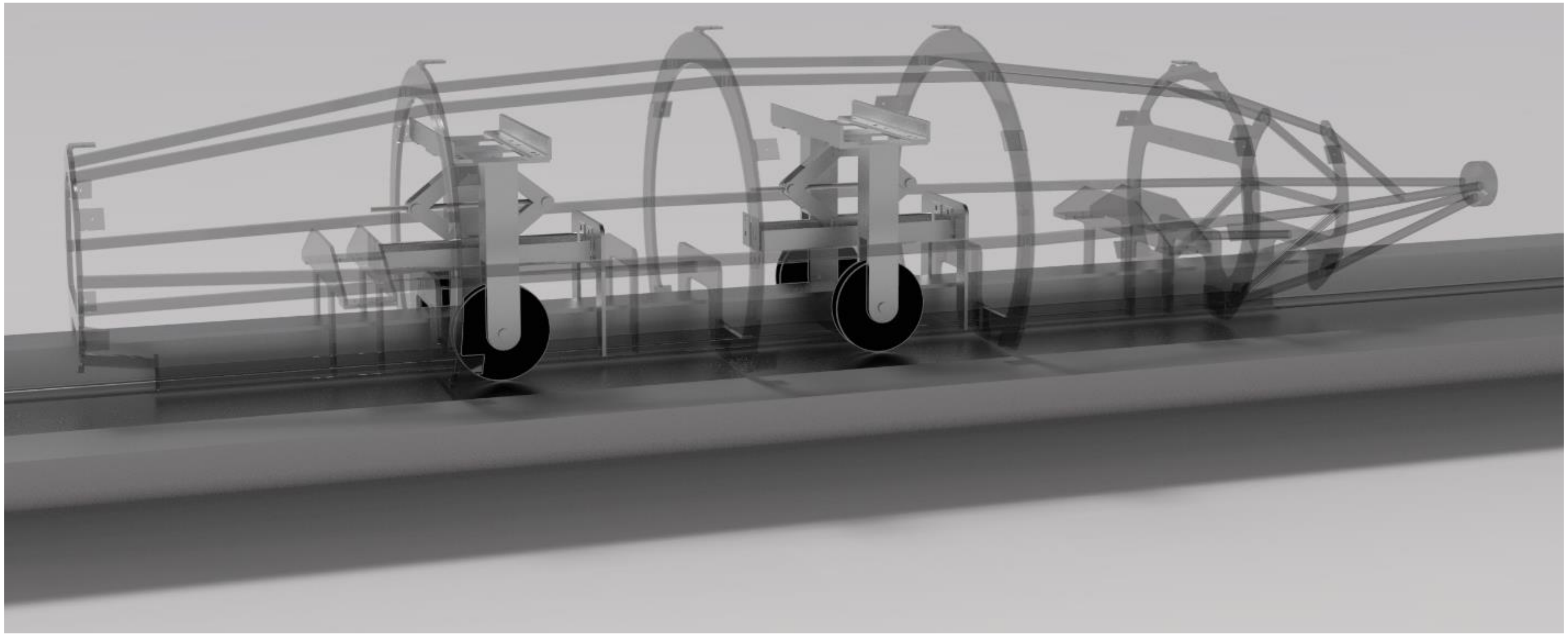






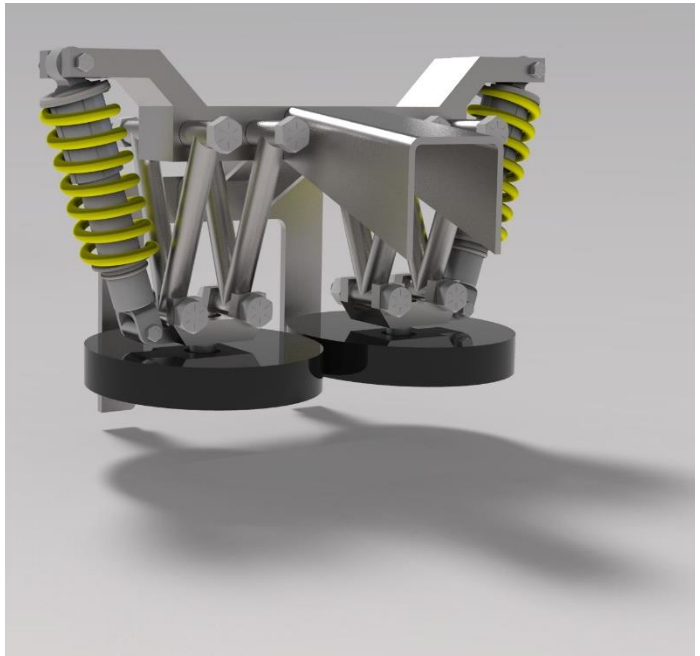
SERVICE WHEELS

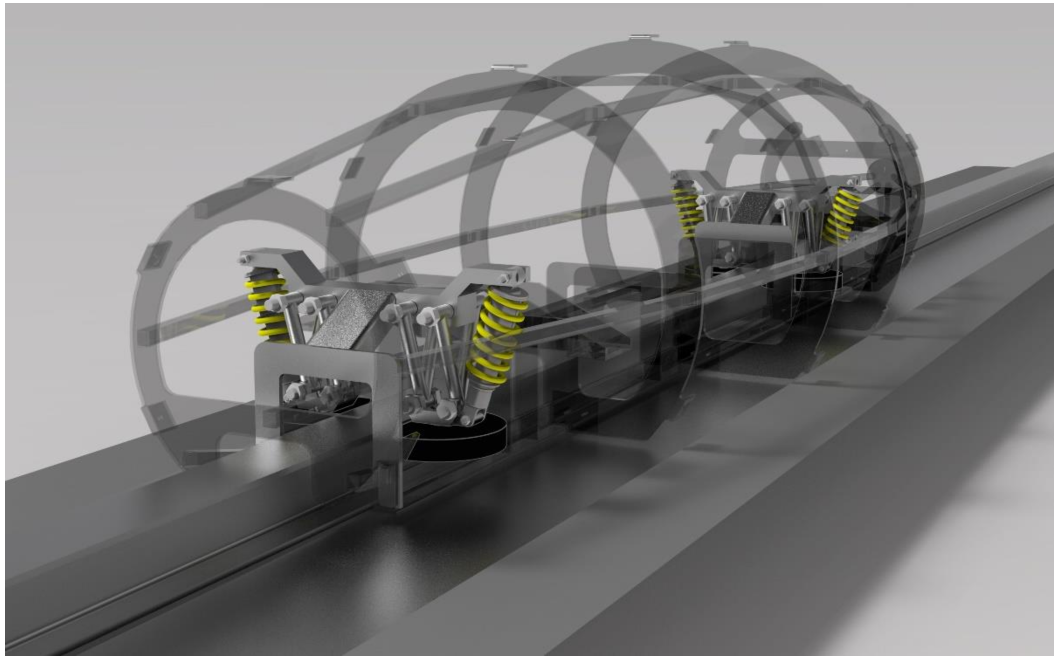
- Powered service wheels for transport and potential pod recovery
- Wheels extend 1/8” below hover engines
- Motorized rear-left support wheel



I-BEAM STABILIZATION

- Benchmarked from roller coaster design and car/motorcycle suspension systems
- Spring-damper resists movement from the parallel linkage
  - Handles lateral forces





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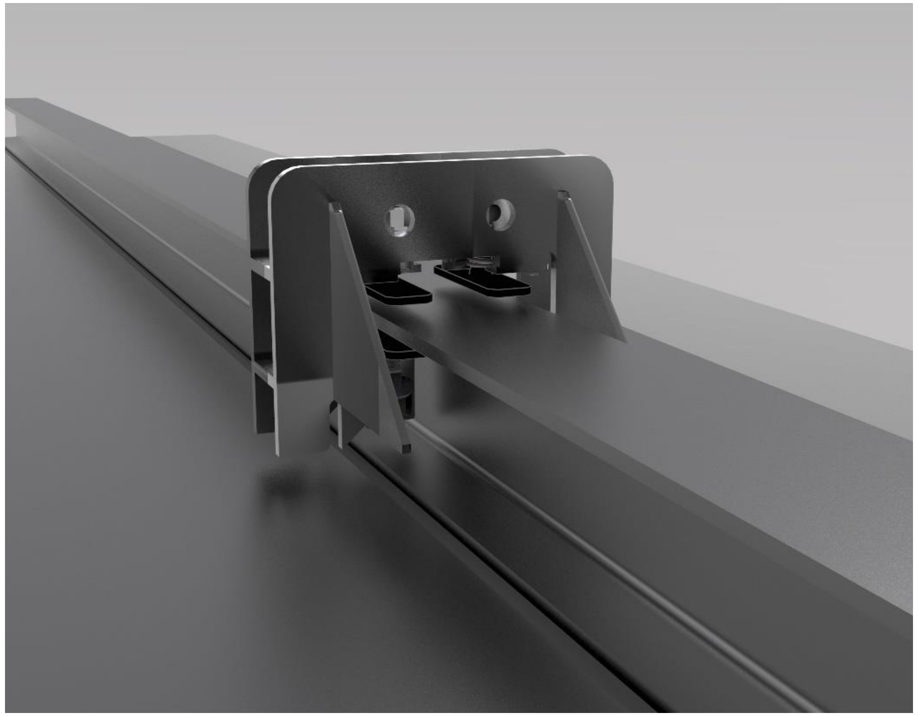
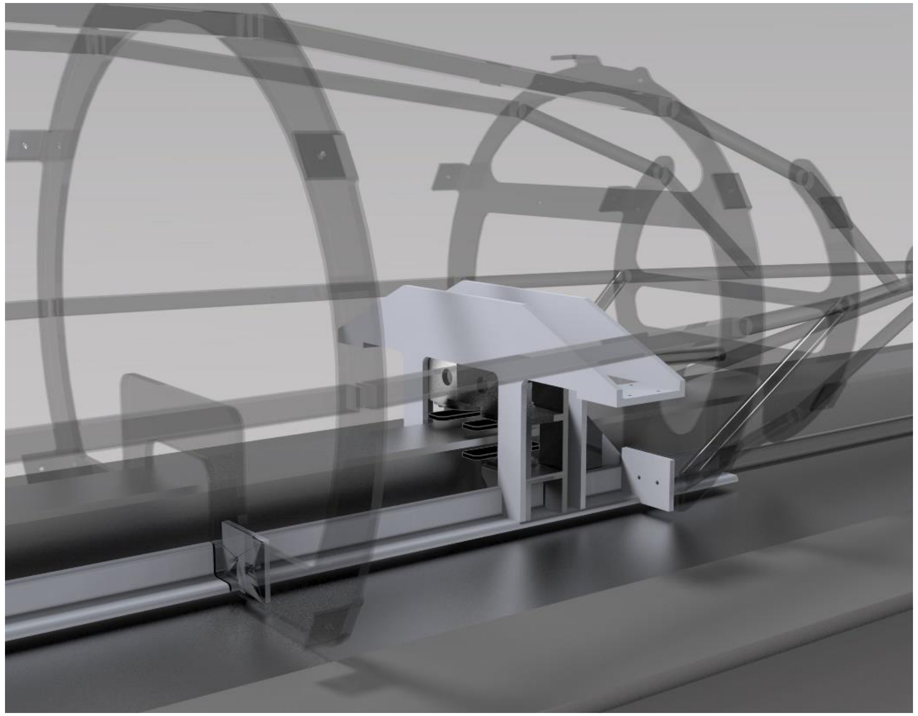
BRAKING

- Pneumatic braking assembly with four actuated brake pads
  - Brake pads clamp onto the I-beam
  - Located at rear of pod





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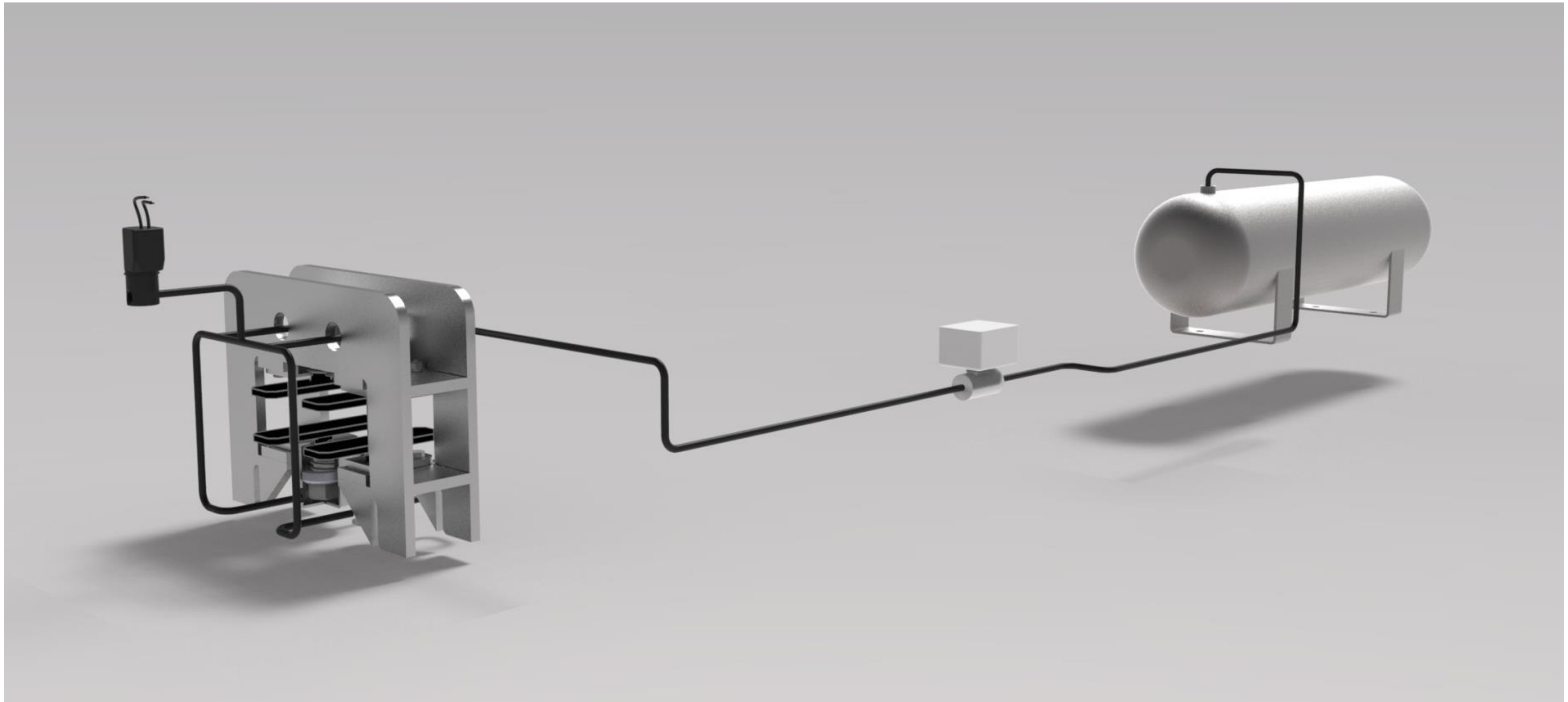
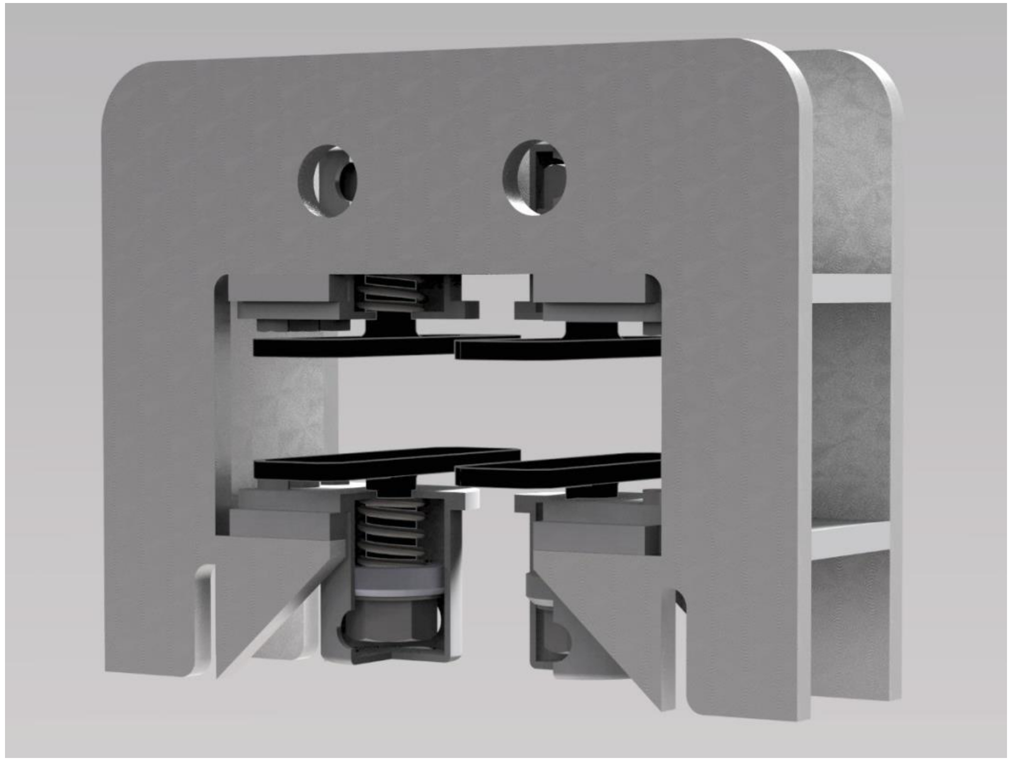
BRAKING

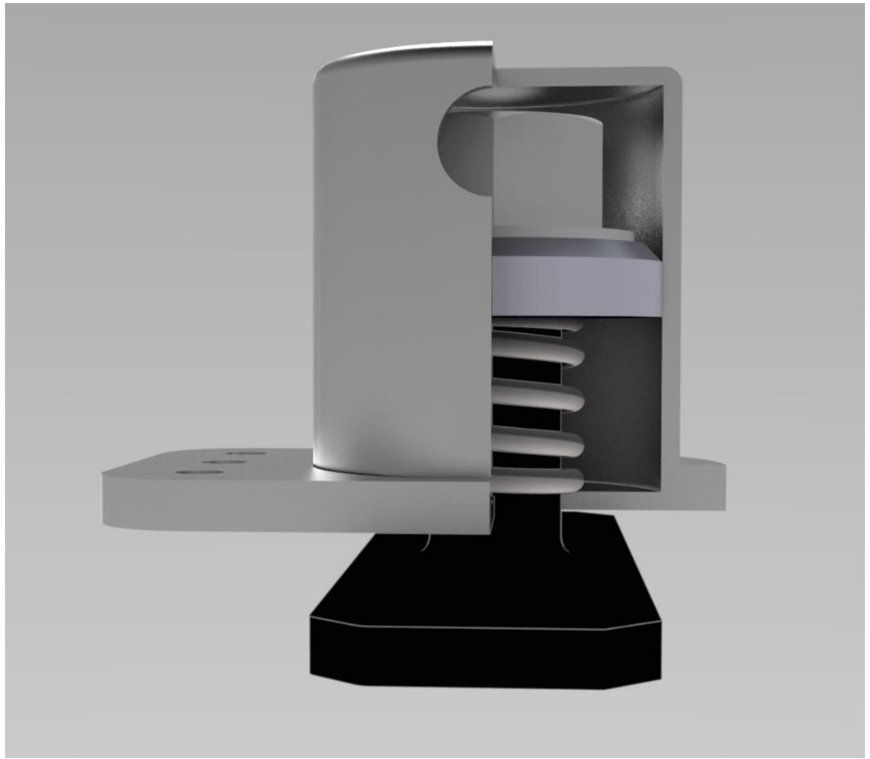
- Pressurized air tank provides pneumatic brake force



BRAKING

- Braking automatically activated by solenoid valves if power fails
- Ball valve manually disengages the brakes





POD WEIGHT

Subsystem	Weight
Frame	66 lbs
Shell	83 lbs
Service Propulsion Wheels	96 lbs
I-Beam Stabilization	60 lbs
Braking	27 lbs
Magnetic Levitation Engines	60 lbs
Battery and Electronics	63 lbs
Total Weight	**455 lbs**

MAGNETIC LEVITATION

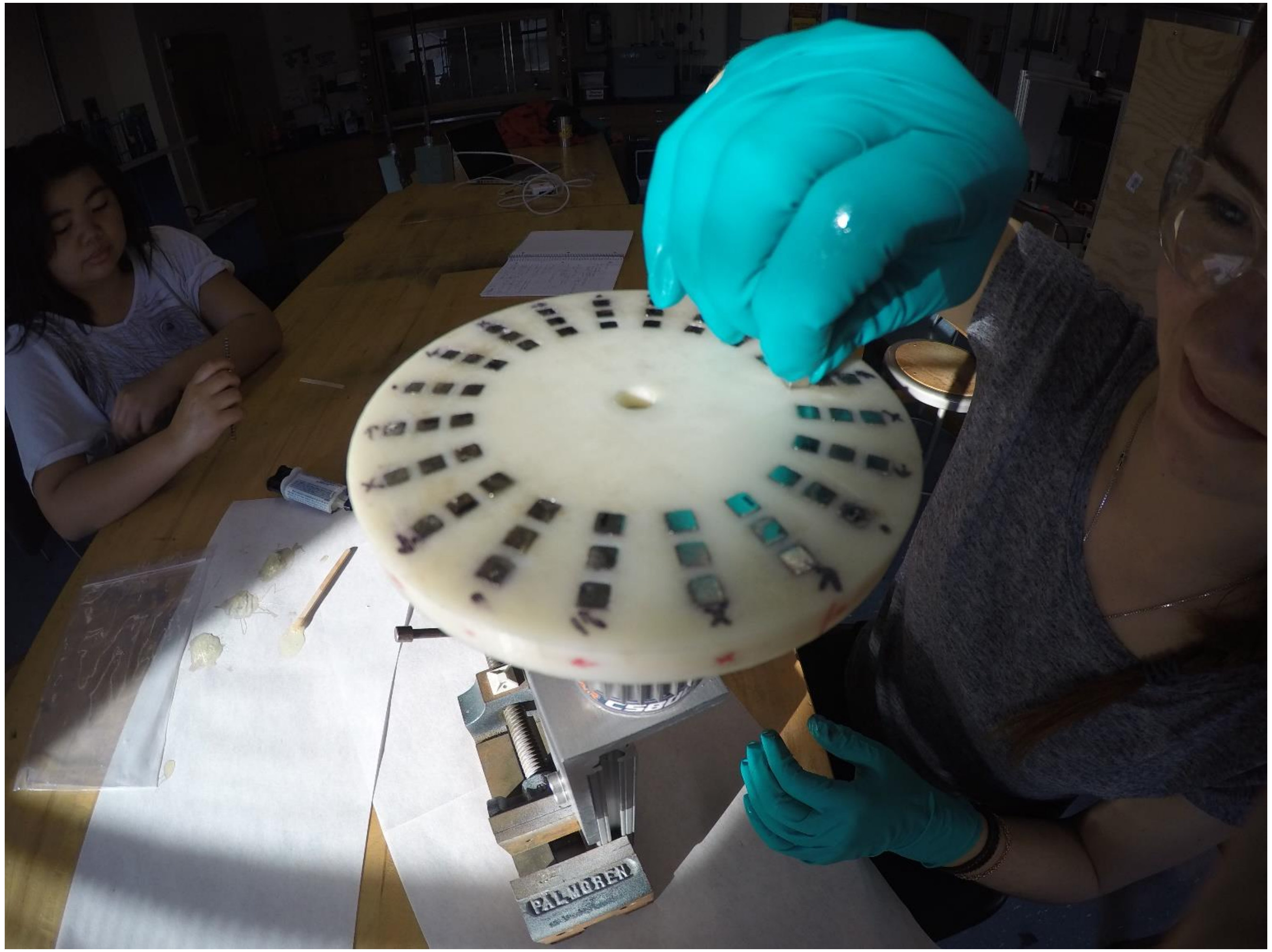
- System utilizes four Arx Pax Magnetic Field Architecture (MFA) hover engines
- Electronically adjustable hover height
  - Aiming for 0.20” (5mm) pending further testing
- Four engine payload
  - 550 lbs

MAGNETIC LEVITATION

- Best chance of success for competition while still adhering to the future scalability of the Hyperloop
  - Operate at high speeds and in low-pressure environments
  - Levitation + Propulsion + Braking + Control

Arx Pax HE3.0 Hover Engine

MAGLEV PROTOTYPING



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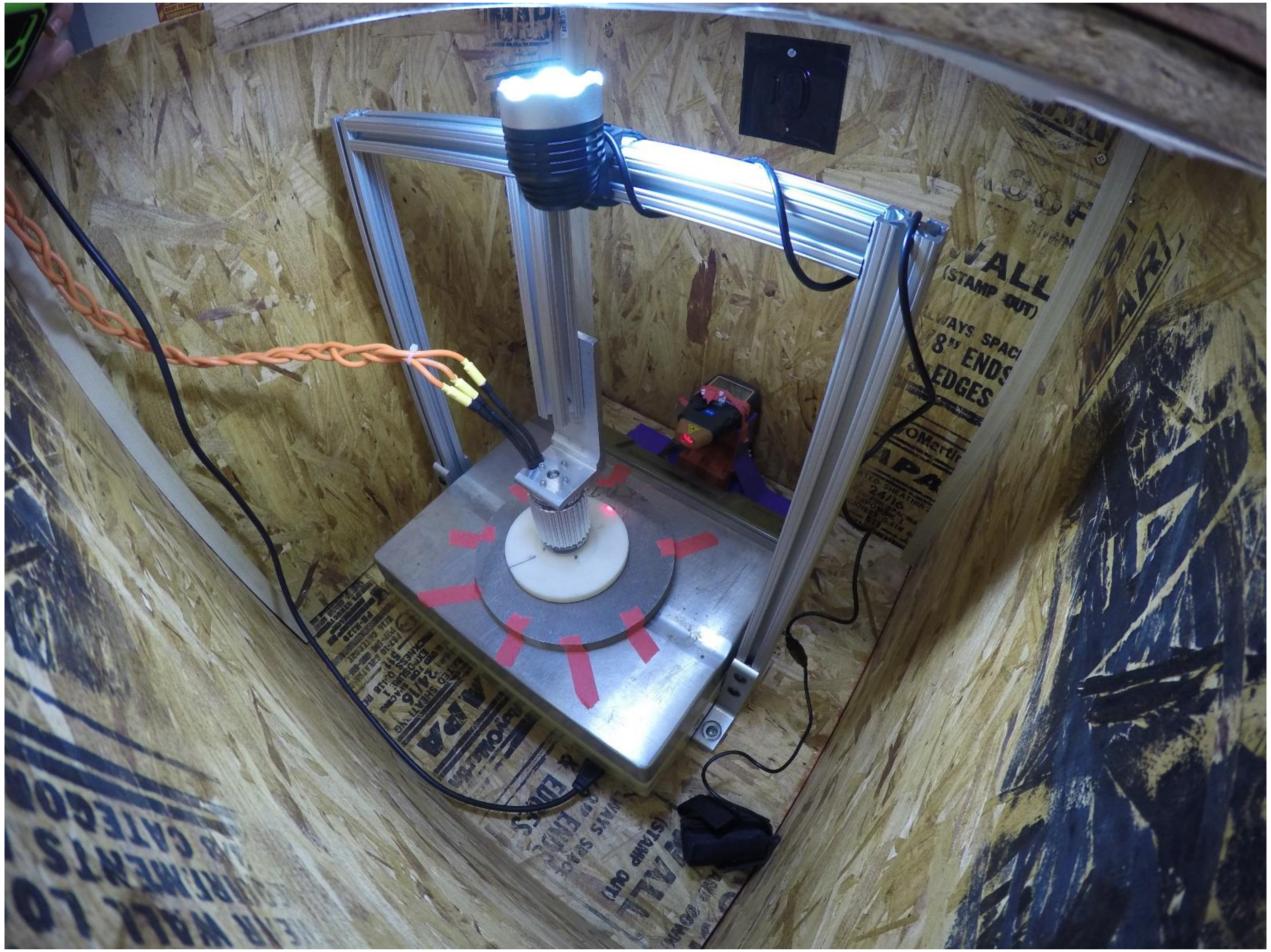
MAGLEV PROTOTYPING



MAGLEV PROTOTYPING

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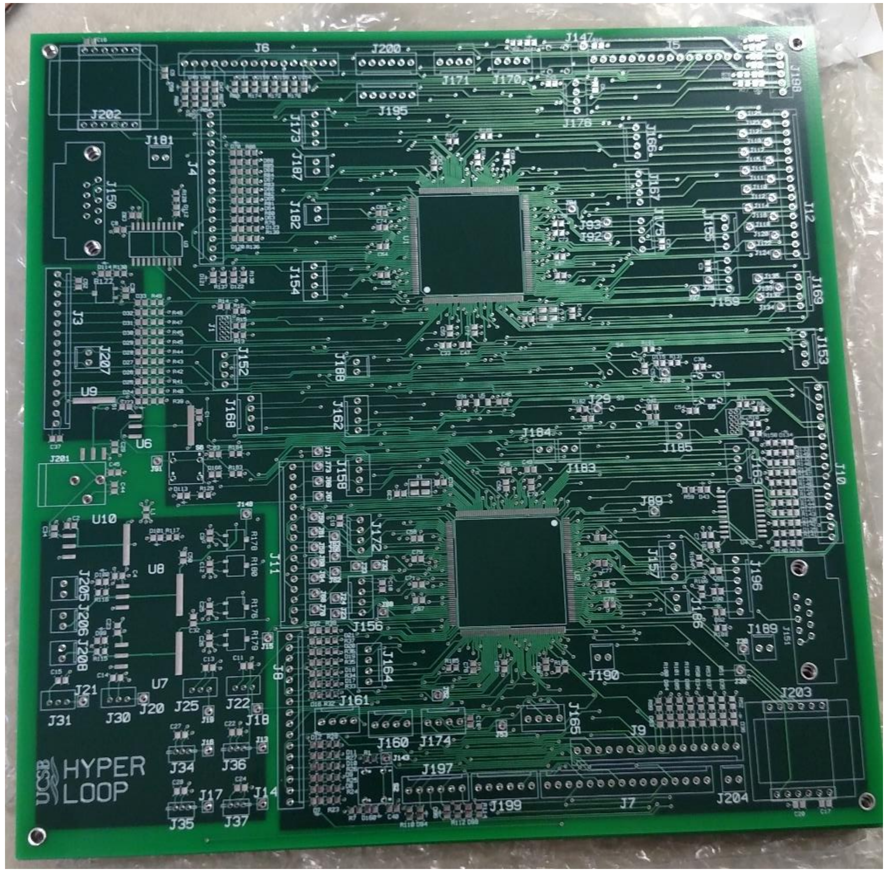
SYSTEM CIRCUIT BOARD

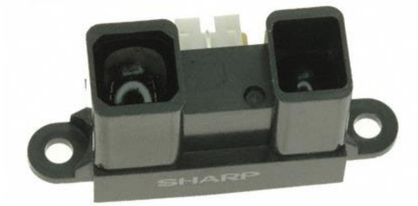
- 8.1” x 8.1” printed circuit board
  - (2) LPC NXP4088 microcontrollers
  - Actuation
  - Sensor interface
  - Communication
  - Pod-stop command
  - Control systems

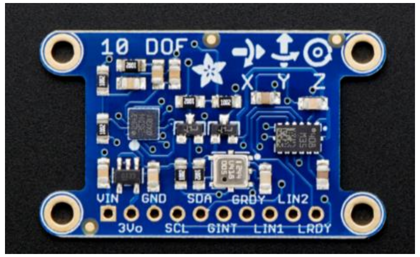
- Already fabricated and awaiting assembly



SENSORS

- **Photoelectric sensor***:*
  - Detects reflective strips on top half of tube
- **Short-range ranging sensor***:*
  - Determines height relative to bottom of tube
- **Long-range ranging sensor**:
  - Gives position relative to sides of the tube
- **Consolidated Board**:
  - Accelerometer
  - Gyroscope
  - Barometer
  - Thermometer

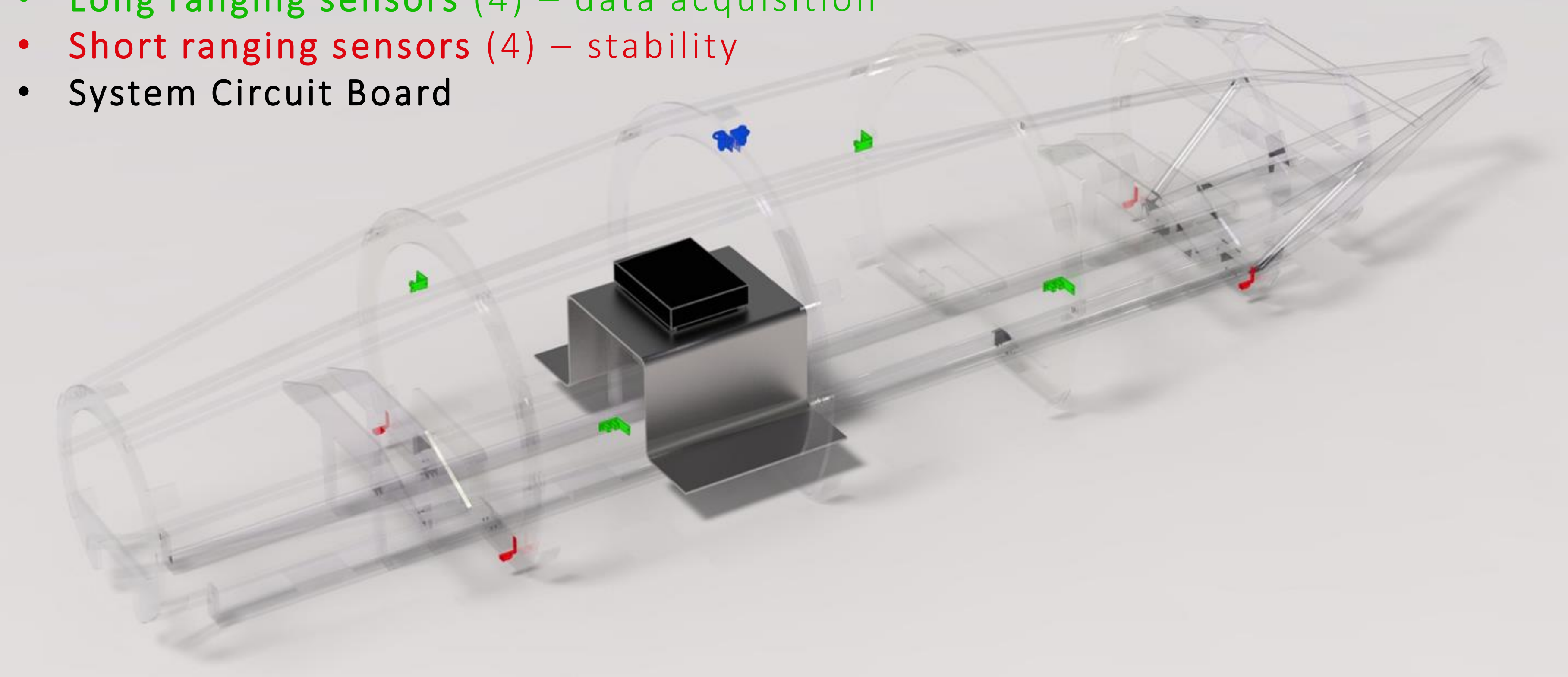




Introduction
Frame
Shell
Propulsion
I-Beam Stabilization
Braking
Weight
Levitation
Electronics
Controls
Power
Production
Conclusion

SENSOR LOCATIONS

- Photoelectric sensors (2) – navigation
- Long ranging sensors (4) – data acquisition
- Short ranging sensors (4) – stability
- System Circuit Board



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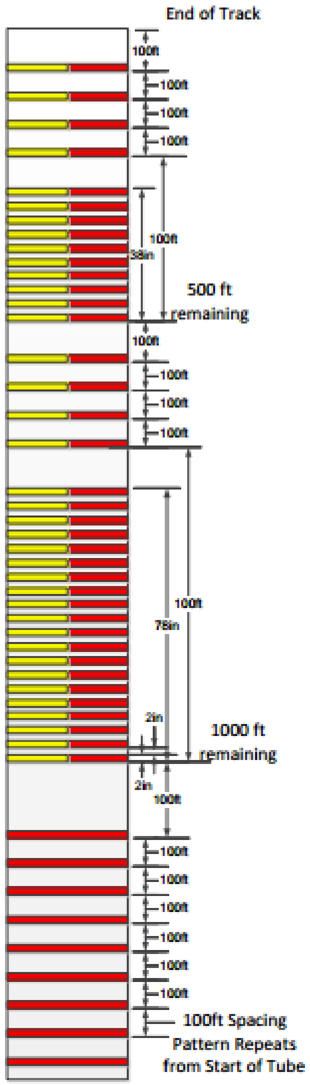
PROTOTYPING

- Currently prototyping sensors on LPC NXP4088 Developer’s Kit
- Testing cabling constraints on a full-sized model

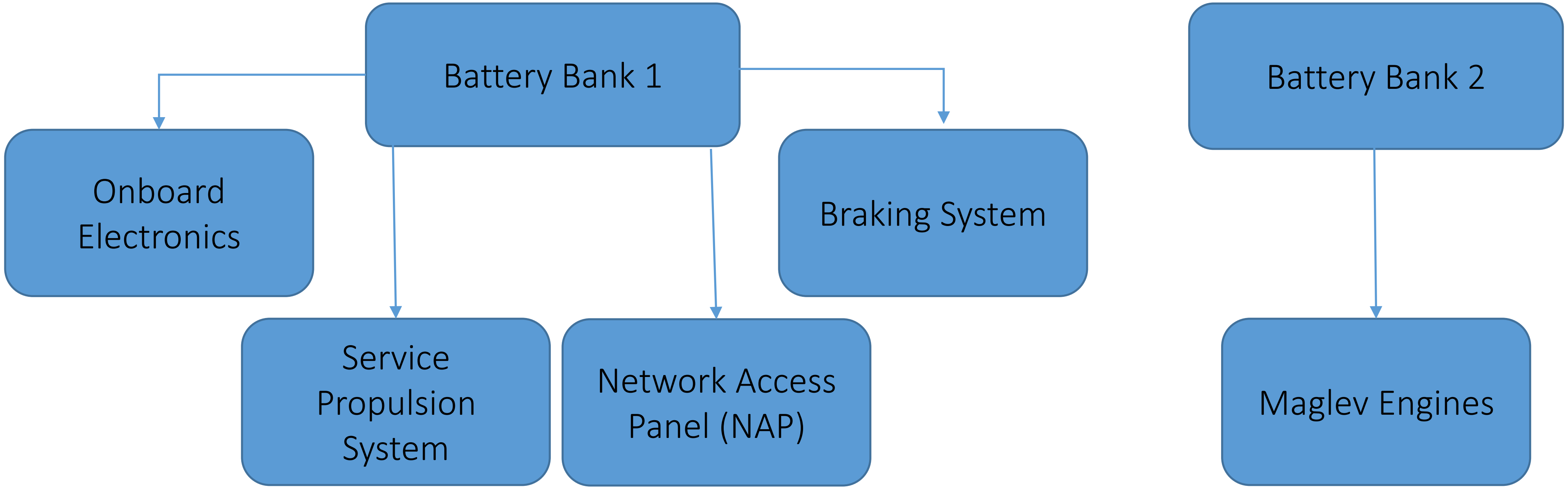
CONTROL SYSTEMS

- Navigation
  - Absolute position with photoelectric sensor
  - Double integrate accelerometer between strips
- Stability
  - Absolute position with short range ranging sensors
  - Relative position with gyroscopes
  - Adjust each engine's levitation to maintain stability and correct disturbances
- Braking
  - Microcontroller activates/disengages brake system solenoid
  - Automatically applied if connection lost for >5 secs

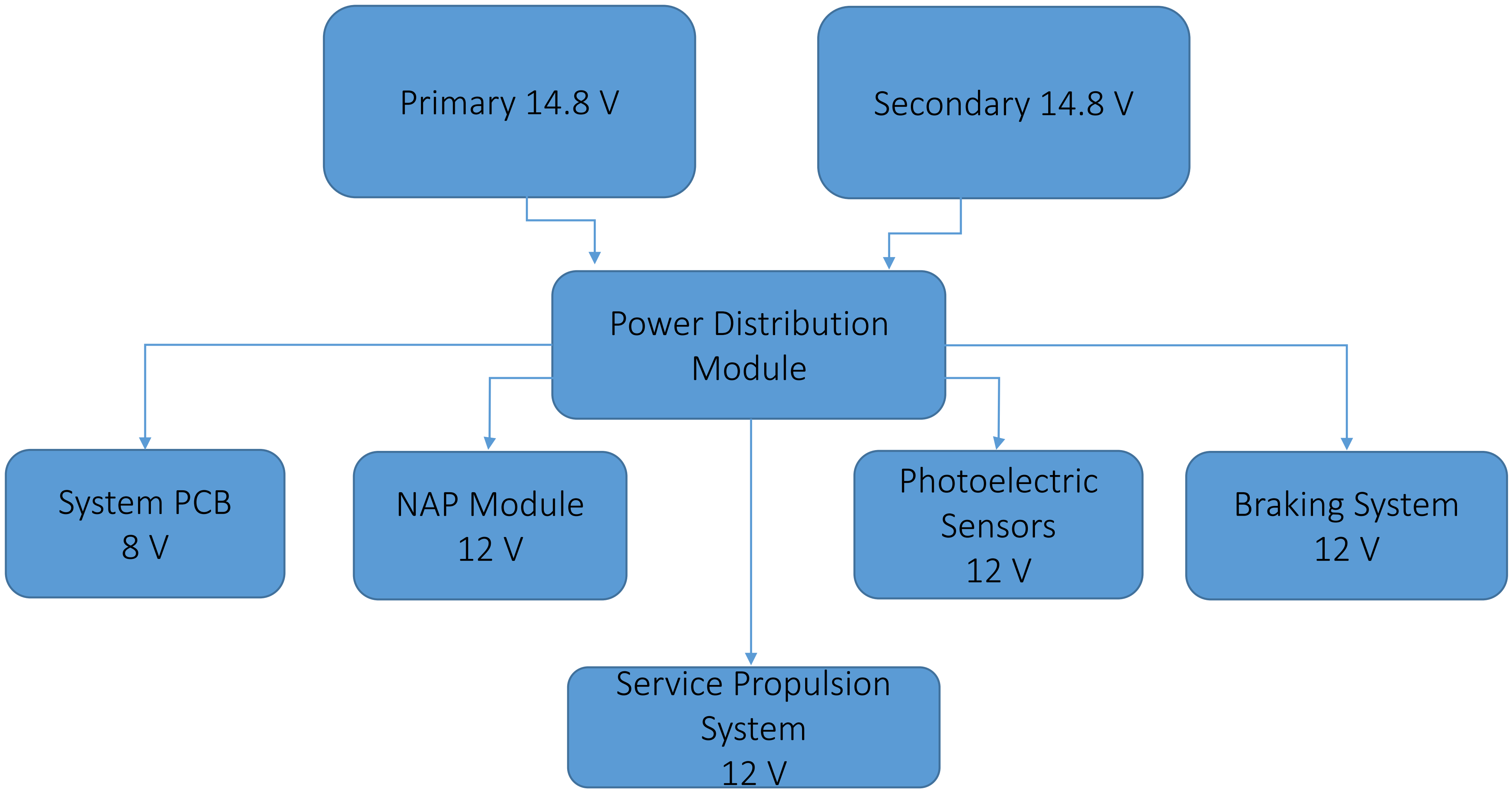


POWER SYSTEM

- **Battery Bank 1**
  - Onboard electronics, NAP, braking, service propulsion
- **Battery Bank 2**
  - Magnetic levitation system

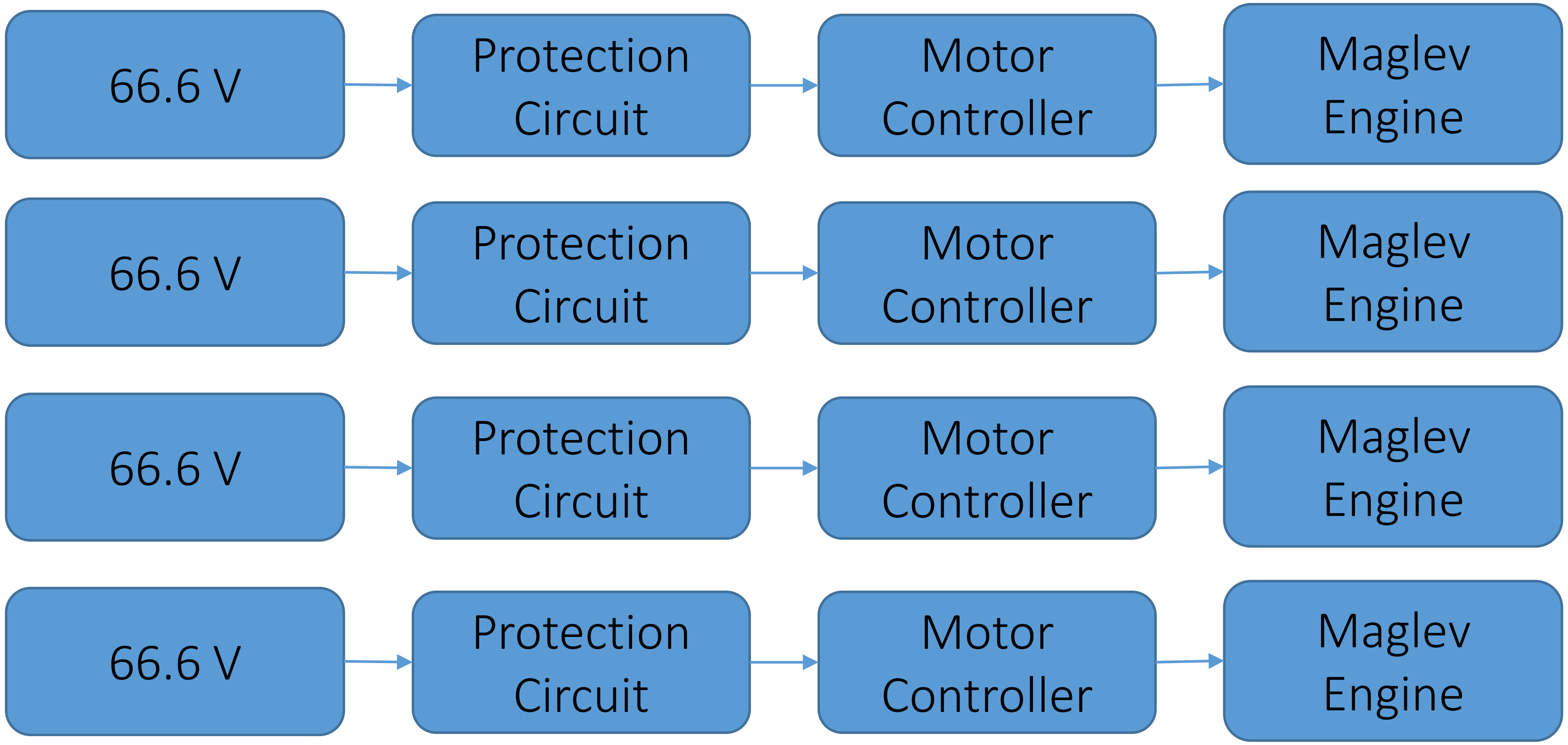


BATTERY BANK 1



BATTERY BANK 2

- Independent power supply for each engine
  - 20Ahr capacity (per engine) for 26.2 min of levitation
- Protection circuit to prevent battery over-discharge
- Motor controller communicates with System PCB



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BATTERY SELECTION

- Lithium polymer (LiPo)
  - Battery of choice for quadcopter/drone applications
    - Optimal capacity/weight ratio
    - High discharge rating
    - Easily obtainable off-shelf packs
  - Fire safety
    - Fire resistance bags encase each battery bank
    - Stainless steel LiPo charge box to prevent battery puncture in the event of a crash

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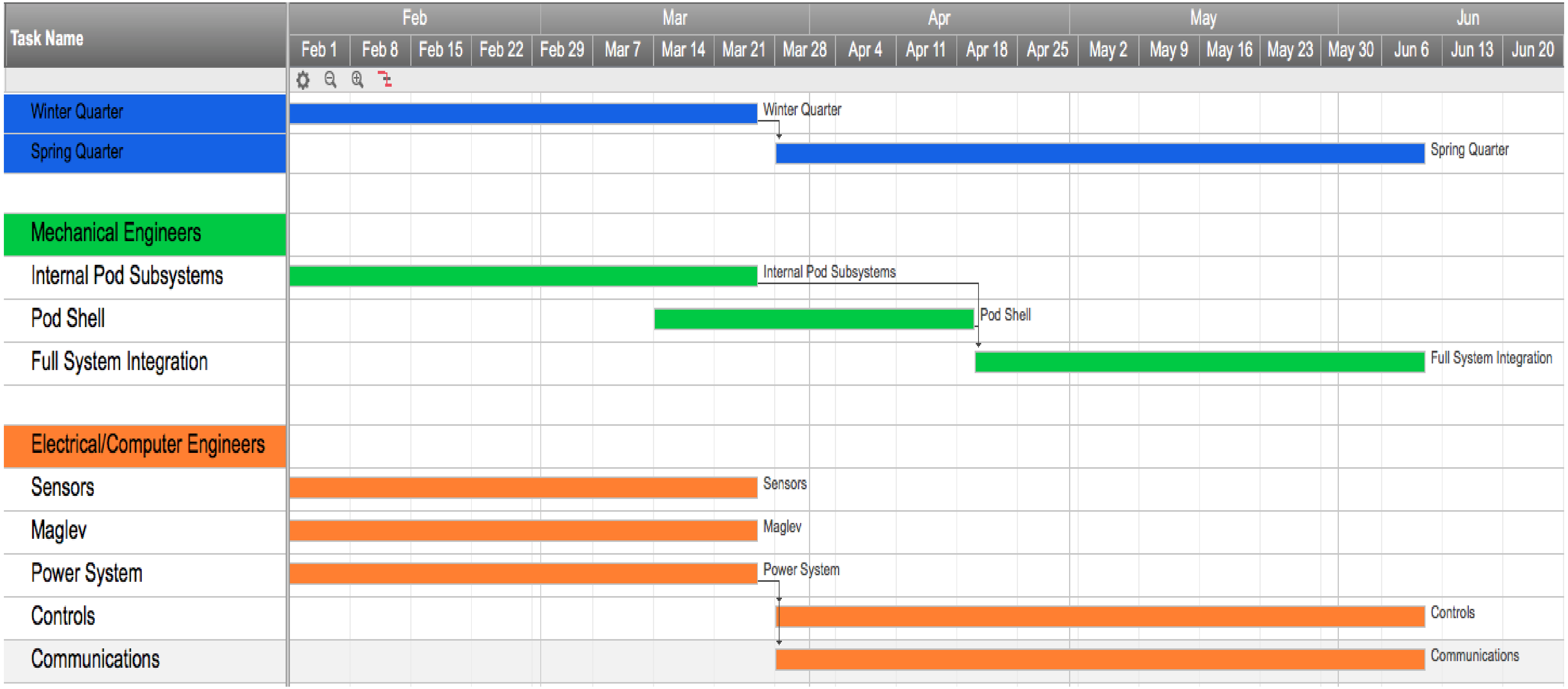
PRODUCTION SCHEDULE



CONCLUSION

- Work began in October 2015
  - With school schedules—effectively 12 weeks of work

- Accomplishments
  - **Raised $15,000—need $25,000 to reach goal of $40,000**
  - Printed Circuit Board is in assembly
    - Prototyping sensors with NXP Developer's Kit
  - 3D printed model
    - Used for extensive wind tunnel testing
  - Magnetic levitation testing & prototyping
  - Styrofoam and PVC pipe model of frame completed
    - Beginning to work with cabling
  - Established a finance/marketing team

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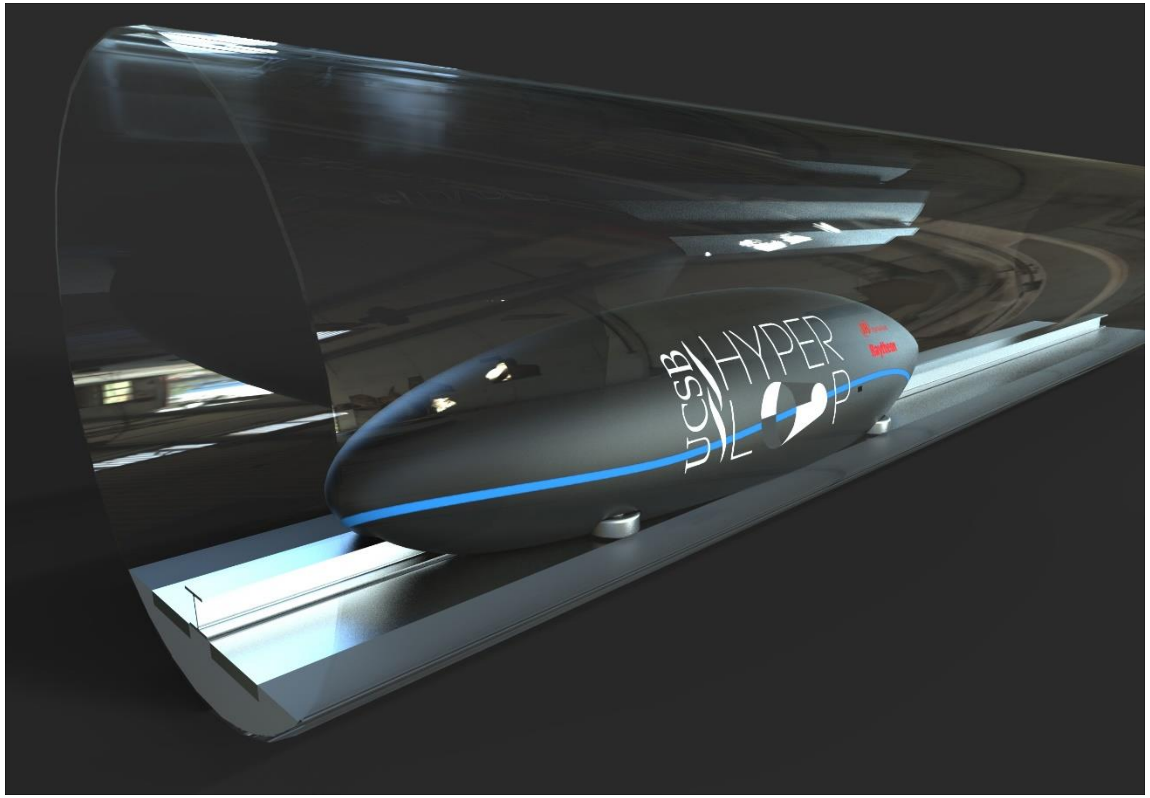
CONCLUSION

- Thank you to our mentors and our sponsors.
- Please find us at Booth 64 or contact us:
  - ucsbhyperloop@gmail.com
  - ucsbhyperloop.com
  - @UCSBHyperloop



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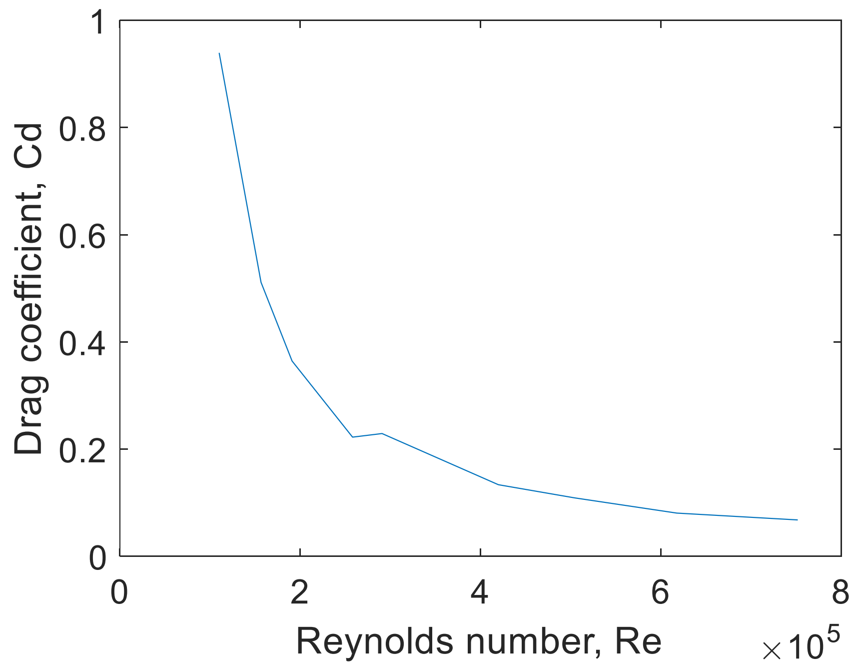
SHELL

wind tunnel testing

- Reynolds number in evacuated tube is 8.5×10^3
- Drag force = 6.6 N
- Estimated drag coefficient = 1.5
  - Extrapolated from wind tunnel testing with 3D model

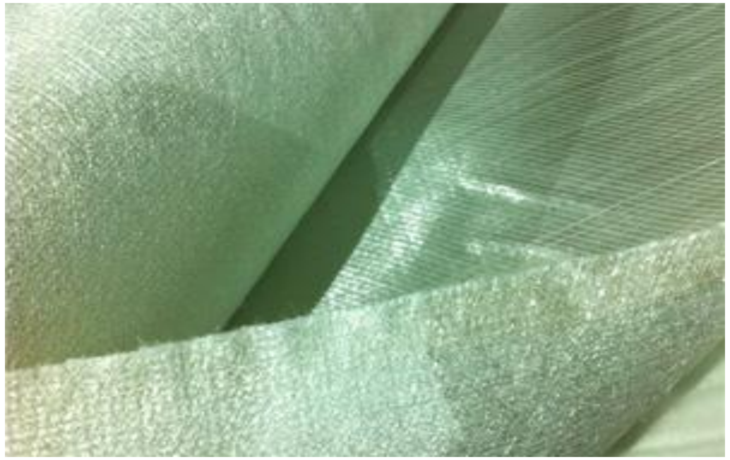
- If tube becomes pressurized, highest anticipated Reynolds number is 6.2×10^6
  - Drag force = 160 N



SHELL

material

- Selected Fiberglass: E-Glass reinforced polyester with a non-crimp laminate
  - Manufactured with a wet resin process
  - Quasi-isotropic material: evenly strong in all directions
    - Shell's curved surface experiences force in multiple directions
  - Yield and tensile strengths range from 29.2 ksi to 42 ksi
  - Pricing at $0.95 -$1.04 USD/lb



VACUUM COMPATIBILITY

problems

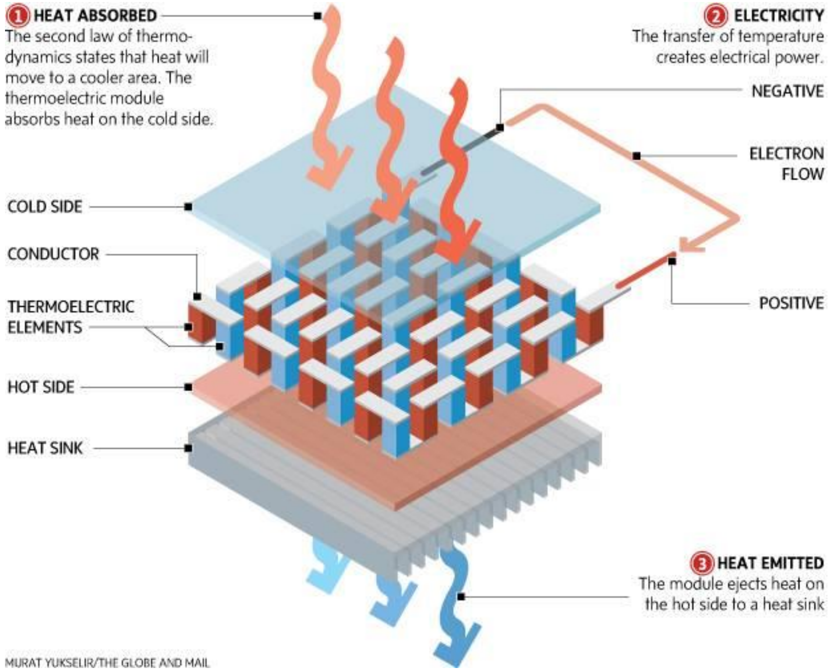
- Heat dissipation
  - Low convection at 0.02 psi requires other cooling methods
    - Maglev engines
    - ESC (electrical speed controller) for maglev engines
    - Battery banks
    - Processor
    - Sensors
- Depressurizing sealed components
  - Specific components will be tested and recalibrated to ensure they work safely in a vacuum
    - Fiberglass shell
    - Battery case
    - Spring dampers
    - Air tank used for brakes

VACUUM COMPATIBILITY

solutions for heat dissipation

- Liquid cooling (active and passive)
  - Submersion
  - Heat pipes
- Canisters of Nitrogen
- Phase change heat sinks
- Peltier tiles

- Methods of choice are contingent on future testing and budget constraints
  - Liquid cooling is currently the best option



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THERMAL PROFILE

- Battery
  - Each LiPo battery has a nominal 30mΩ internal resistance
  - Batteries are in a 2 series-3 parallel configuration, giving 20mΩ total resistance
  - At peak draw the 4 engines will pull 600A total
  - Using $\mathrm{P} = I^2 R$, the thermal output will be 7200W
  - Cooled using a single-phase pressure tight water loop around the packs
- Maglev Engines
  - Majority of the energy is transferred into the substrate
  - Mounting maglev engines on a heat sink to control thermal output

VIBRATION ENVIRONMENTS

- The flow in the tube will be turbulent (Re = 8700)
  - Turbulent flow leads to vortex shedding
  - Von Karmann equation gives vortex shedding frequency as 8.7Hz
    - Assumes the pod is a cylinder turned sideways perpendicular into the flow
- Frequency is comparable to the natural frequency of the I-beam stabilization system (5.9 Hz minimum), however:
  - Low air density means low aerodynamic forces
  - The pod is more aerodynamic than a cylinder, so vortex shedding should be negligible
- Vibrations from the maglev engines are of little concern as their speeds will be much higher than any natural frequencies (~5000RPM = 83Hz)

LAUNCH LOGISTICS

loading & unloading

- 100 miles from UCSB campus to Hawthorne—rent a U-Haul

Loading procedure

1. Team members roll pod up to staging area using service wheels
2. Lift onto platform using SpaceX crane
3. Motorized safety wheels propel pod into tube
4. Manual engagement of braking system performed by team member (once pod is on I-beam, before SpaceX pusher is connected)

Unloading procedure

1. Motorized safety wheels drive pod onto Exit Area from its ending position in tube
2. Remotely power-down motors while maintaining power to brakes
3. Manually release brakes
4. Remotely power down all systems
5. Lift pod off of Exit Area using SpaceX crane

LAUNCH LOGISTICS

failure conditions

Test Phase A-D failures:

- Pod unloaded following reversed Loading Procedure steps

Launch failures:

- Pod stops far from end
  - Use service wheel system to extract
- Pod stuck with no power or no communications
  - Send rescue team to manually push out using service wheels
- Pod crash
  - Send rescue team to retrieve damaged pod

SAFETY FEATURES

tube breach, rapid depressurization

- In the event of a large leak (assuming cross sectional area has been cut), the large pressure difference will force the air to choke to the speed of sound
- Since the atmosphere drops in pressure as it moves through the hole, the effective rate at which the atmosphere leaves is at about 60% of the speed of sound (~ 650 meters/second)
- Fiberglass shell designed to withstand pressure to a Factor of safety of 4000

Breach Pressure Force $= \mathrm{A}\rho\mathrm{V}^2$

A = 0.65 m^2

ρ = 1.225 kg/m^3

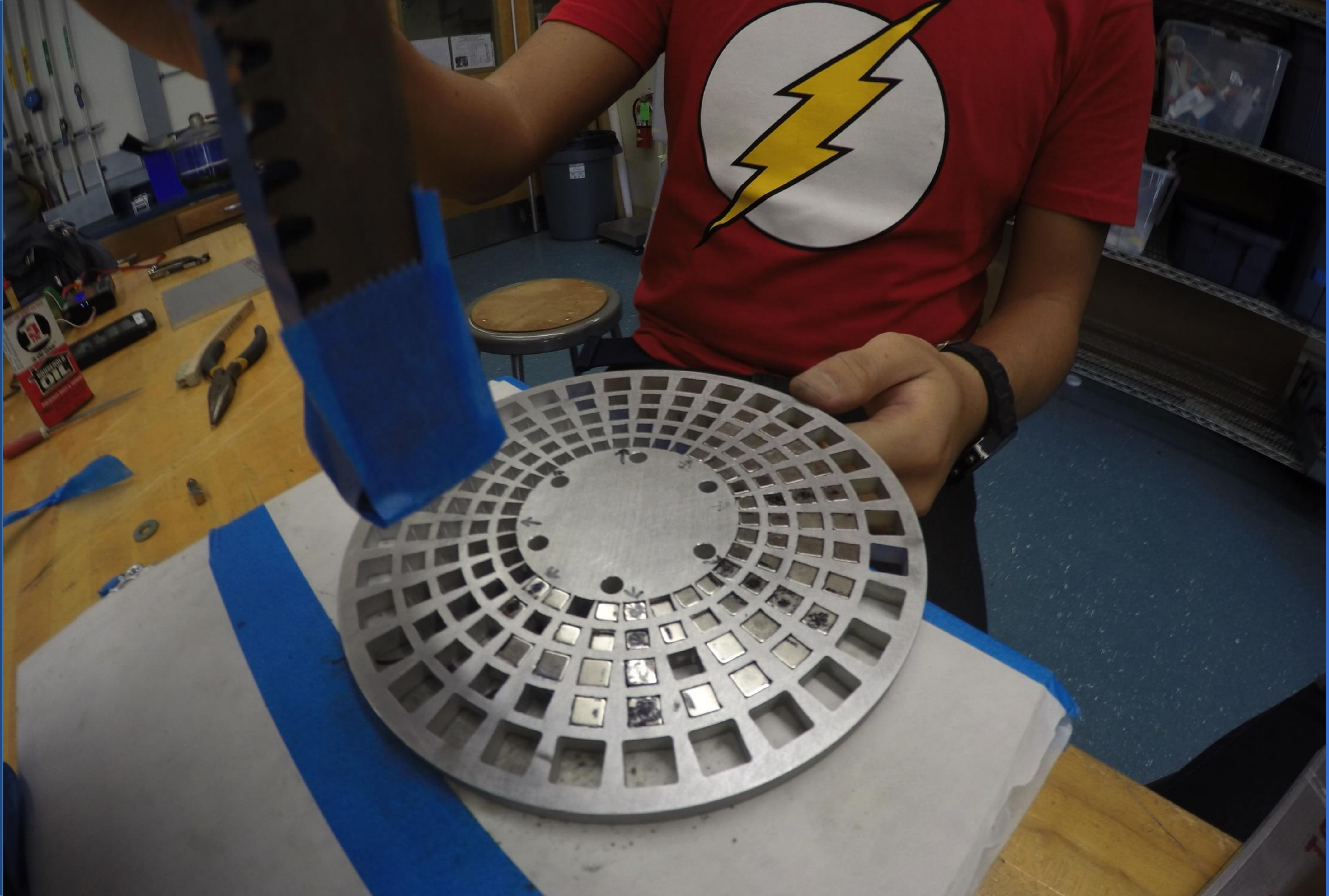
V = 200 m/s

Breach Pressure Force = 31850 N

Stress on frontal area = F/A = 49 kPa

Yield strength of fiberglass = 200 MPa

Surface Force = 4000



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